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ON

BONE AND ITS USES IN THE ARTS.

By THE SECRETARY.

Read 13*th November*, 1838, *and* 8*th January*, 1839.

Most animal bodies are composed of soft and hard parts; of the latter, some are hard only when of a certain thickness, but when thin are tough and more or less flexible and elastic: such as the horns of all mammalia (except of the stag tribe); the claws of the lion and tiger; the talons of the eagle; the horn of the rhinoceros; the coriaceous covering of tortoises and crocodiles; and the scales of fishes.

All these, by exposure to a gradually increasing heat, soften, enter into pasty fusion, give out the odour of burnt feathers, burn with jets of flame, and are consumed, leaving behind a very small proportion of earthy matter. 500 grains of horn leave not more than from 0·25 to 2 of phosphate of lime. Boiling-water, after long action, takes up from most of them scarcely any quantity of soluble matter, but they are perfectly soluble in caustic alkali, and the solution gives, with acids, a curdy precipitate. They are considered, therefore, as composed of condensed membrane, or, in chemical language, of albumen.

Other hard parts are rigid, considerably harder than the former: when dry, and in many cases when wet, they are very slightly flexible or elastic; and when struck by a hammer, or when bent beyond their power of resistance, break short with a splintery surface. When exposed to a red heat, with access of air, the membranous or animal part is destroyed; but the earthy part remains in sufficiently abundant quantity to retain the external form, and generally the internal structure, of the entire substance, of which calcined bone and calcined oyster-shell are examples. The original hardness of these parts is owing to the abundance of earthy matter that enters into their composition. When such parts are on the outside of the body, they are called, in common language, shells, horns, teeth, according to their position; and the uses for which they seem intended. When they occur within the body, they are called bones.

If, however, we restrict the term bone to its common meaning, we shall exclude the horns of the stag kind, and the substance which forms the body of most teeth, both which are truly bone, and shall include some substances, such as cuttle-fish bone, which is truly shell.

It is, therefore, necessary to enter into a more minute examination and comparison of these hard substances, in order to ascertain which of them are shell and which bone; and, as the result of our inquiry, we shall probably find, with respect to this class of natural bodies as with many others, that although the two extremes of the series are readily enough distinguishable from each other, yet they approach by such insensible intermediate gradations, as to render it impossible to say where the one begins and the other ends.

There is a class of shells comprising most of the univalves, which are harder than other shells, and when broken present thick, parallel layers, the layers themselves having usually a finely fibrous structure at right angles to the external surface. These fibres may often be seen to be nothing more than the transverse section of thin transparent parallel lamellæ, which, when viewed on their broad surfaces, often exhibit the usual natural joints of calcareous spar. When such a fracture is viewed by the naked eye, it has a good deal the appearance of porcelain, — whence their name of porcellanous shells. When carefully cleansed from all remains of the animal which inhabited them, they give out scarcely any perceptible odour on being made red hot, though their colour becomes somewhat grey. When unaltered they dissolve in dilute acid with much effervescence of carbonic acid gas, and a few hardly appreciable gelatinous flocks remain undissolved. These latter, on being collected and washed, give out, when heated, a faint odour of burnt animal matter, and become black before they are consumed. By proper chemical tests the soluble part of the shell is proved to have been carbonate of lime or chalk, the particles of which were cemented together with a very minute portion of animal mucus.

Another class of shells is the nacreous, so called from the varying and iridescent colours that they exhibit, resembling those of nacre, or mother-of-pearl; this very substance being, indeed, only a part of a nacreous shell.

These, when heated in a crucible, give out the odour of burnt feathers, often with a perceptible smoke, become of a dark-grey colour; and when submitted in this state to the action of acids, there remains undissolved a notable quantity of charcoal. In the recent state they effervesce with weak acids; and when the calcareous matter has been removed, there remains a series of flexible, membranous, or semigelatinous lamellæ, lying parallel to one another, and representing the form of the entire shell. These lamellæ have sometimes a distinctly fibrous structure, parallel to the surface of the shell; and though quite flexible while moist, they shrivel on drying, and become hard like horn,—a substance to which they bear the greatest possible analogy. The nacreous shells, therefore, are always very finely lamellar in structure, and are represented by some as composed of alternate layers of membrane and carbonate of lime; but the more probable opinion is, that the calcareous matter is intimately mixed with the membrane, rather than distinct from it. These shells increase in size, in order to accommodate themselves to the growth of the animal, by the deposition of new and larger layers from within; and hence the external surface is covered by concentric furrows or wrinkles, marking the outer margin of each successive layer.

Between the two classes of shells that I have described are others, the minute structure of which I am ignorant of, but which differ considerably in the proportion and condition of their membranous ingredient.

Thus it appears that all shells, how much soever they may differ from one another in structure, agree in containing carbonate of lime as their only earthy ingredient; and an animal substance, nearly resembling if not identical with, horn or membrane, as their consolidating or agglutinating ingredient.

Exactly the same substances, namely, carbonate of lime and membrane, in various proportions, form the constituent materials of the madrepores and other hard corals.

On examining the hard covering of aquatic crustaceous animals, such as the crabs and lobsters, we find, after the action of acids, that there remains a whitish, soft, elastic cartilage, which represents the original shape of the part, and that the acid solution not only contains lime that had been in the state of carbonate in the original shell or covering, but likewise phosphate of lime, although in smaller proportion than the carbonate. The presence of this earthy salt forms an essential difference in chemical composition between proper shell and the covering of the crustacea, which latter substance may thus be considered as holding an intermediate position between shell and bone.

Some of the corallines, chiefly those belonging to the genera *Gorgonia* and *Antipathes*, approach still nearer in chemical composition to bone; and, indeed, are hardly to be distinguished from it, their earthy part being phosphate of lime with only a small admixture of carbonate, their figure and structure being represented by dense membrane, and, when boiled, they give out a notable quantity of true jelly, which, like other kinds of animal jelly, has the property of forming a precipitate with infusion of galls or of oak-bark.

The proportion of membrane in these substances varies considerably, so that while one species almost exactly agrees in composition with the horn of the stag, others contain so much membrane in proportion to earthy matter, as to be nearly identical with the bone of the cartilaginous fishes.

If a piece of true bone, in an unaltered state, be put into weak acid (muriatic acid, on the whole, is the best), a moderate degree of effervescence will take place, shewing the presence of some carbonate. By a continuance of this process for some days all effervescence and chemical action will cease: what remains undissolved will still represent the size and form of the original bone; but it will be semi-transparent, will exhibit a distinctly cellular structure, will be soft, flexible, and, to a certain degree, elastic. If, after being washed, it is boiled in water, it will be found to be in part soluble; and the solution, when boiled down to a proper consistence, will become viscid, and will gelatinize on cooling, and by drying will be brought to the state of hard glue. This jelly, when again dissolved in water, will become curdy and will give a grey precipitate with nutgall, and will exhibit all the other physical and chemical properties of gelatin: the remaining portion insoluble in water will become hard and somewhat brittle by drying, will burn in the fire like a piece of horn, will dissolve in caustic, fixed alkali forming a saponaceous liquid, and will shew all the other properties of albumen or membrane.

The acid in which the bone was first steeped will give an abundant white precipitate of phosphate of lime by means of caustic ammonia, and will give a much smaller precipitate of carbonate of lime by carbonate of ammonia. Thus, by the action of a few simple re-agents, the essential constituents of bone are demonstrated. In this summary I have taken no notice of the oil or fat which is contained in the internal bones of all mammiferous animals, because it seems to be by no means an essential part of bone; the horn of the stag and of other animals of the same kind being entirely free from it. On this account it is that hartshorn jelly, made by boiling the shavings of stags' horn in water, is often recommended to persons of very weak digestion in preference to other animal jellies, as being absolutely free from oil; for, though hard fat is incapable of dissolving in jelly, yet the softer oily fats will combine with it in small proportion.

But, although it is impossible to draw any marked line of chemical distinction between true bone and the indurated membranous textures that I have already mentioned, yet the mode of their origin furnishes a real and very important difference.

Of the organisation of coralline bodies, indeed, we know nothing; for scarcely any of them have been even superficially examined when alive, and, when dried, all trace of structure in the soft parts is completely obliterated.

But with regard to the production of shell, both in univalve and bivalve testacea, we are certain that it never, as such, forms a constituent part of the living animal. A viscid fluid is secreted by certain organs; and it is only when discharged from the body that it assumes the consistence and other characters of shell: therefore, although we may with perfect propriety speak of the structure of shell, as we speak of the structure (that is of the mechanical arrangement of constituent particles) of a crystal, it would be a gross misapplication of terms to speak of the organisation of shell; this latter meaning such an arrangement as is compatible with and necessary for the performance of vital functions. Shell is essentially a dead body, or rather one which never was alive; for though naturalists and collectors well know the difference between what they call a dead shell and another, they mean by this expression merely to point out the difference between an empty shell and one the inhabitant of which was alive at the time of its capture.

The way in which the hard covering of the crustacea is annually formed (for these creatures change their shell every year) has not been sufficiently examined to ascertain whether it is at first a mere exudation which hardens out of the body of the animal, or is an induration of the cuticle by the deposition in its pores of calcareous matter conveyed thither by proper secreting vessels. If the former is the case, the shell of the crustacea is analogous to that of the testacea; if the latter, it somewhat resembles bone in the mode of its formation.

With regard to bone itself, there is no doubt that it is as truly organised and vital as any other part of the body. As soon as the rudiments of a young animal can be distinguished before its birth, the place of the future bone is indicated by a soft or semi-fluid matter inclosed in a delicate membrane: by degrees both the membrane and the matter which it incloses become more dense and cartilaginous; opaque white spots then appear, which soon after are penetrated by vessels carrying red blood: the deposition of bone then begins, and at the same time the cartilage seems to be gradually replaced by membrane. The rudimental bone, which at first was solid, now begins, at least in the long bones, to exhibit an internal cavity or hollow axis; thus shewing that, while fresh matter is continually depositing to supply the growth of the bone, that which had been already deposited is removed, and that this latter process takes place in the interior of the bone at a greater rate than the other does. The activity of the two vital processes of deposition and removal, or, to speak in technical language, of secretion and absorption, is, of course, proportioned to the rapidity of growth; so that, during the early periods of life, the bones participate with the soft parts of the body in the continual change and flux that is taking place within them. When the full stature of the animal is attained, these two actions probably diminish in rapidity, but still are kept up sufficiently to preserve the life of the part. As old age approaches, the removal of the earthy ingredient of bone seems to become more difficult; its proportion, therefore, to the membranous ingredient increases, and hence the bones of old animals are harder, of greater specific gravity, and more brittle than those of younger ones.

That very remarkable natural process, namely, the annual renewal of the bony horns of the stag and other animals of the deer tribe, is, perhaps, the most striking example and illustration of the circumstances necessary to the formation of bone. These horns arise from a short process or pedestal projecting from a bone forming the upper part of the skull, and called the frontal bone. At the season of the year when the horns are about to be renewed, an increase of vital action takes place in the bone, and a faint red line, indicating the presence of blood-vessels, will be perceived in making a longitudinal section of the bottom of the horn and the base on which it stands; the situation of this red line, indicating precisely the boundary between the dead horn and the live bone: absorption of part of the bone takes place, which loosens the adhesion of the horn to it, in consequence of which this latter falls by any accidental shock which it receives. The spongy tissue of blood-vessels, which may now be seen covering the end of the bony base, is soon entirely covered by the growth of the external skin; and this may be considered as terminating the first part of the process. Soon afterwards a small tubercle arises from the end of the bone, and presses upwards the skin which covers it: the tubercle rapidly elongates, the skin extends with it, and in the course of a few weeks it has assumed the size and shape of the future horn: in this state it is covered by the attenuated skin, which latter has pushed out an abundant growth of short fine hairs resembling the pile of velvet. Beneath this skin is a layer of blood-vessels, the diameter of some of which is equal to that of the little finger; these rest on a thin layer of dense membrane, of the same nature as that which covers ordinary bones, and called the periosteum; and within the periosteum itself is a flexible cartilage, penetrated in all directions by ramifications from the blood-vessels already mentioned.

In this state the future horn is very tender and exquisitely sensible, it bleeds when the skin is broken, and the animal often suffers much in this part from the bites of gadflies and other insects. When the cartilage has attained its full growth, ossification begins by the deposition of phosphate of lime, and goes on till the bone or horn has acquired its complete hardness. During this process, a ring of bony beads has been forming at the base of the horn, in the intervals between which the main trunks of the blood-vessels lie: these beads enlarge by the continual addition of bony matter, and in so doing compress the adjacent sides of the blood-vessels, and thus diminish the supply of blood; at length the sides of these vessels are quite squeezed together, circulation ceases, and all the soft parts die, shrivel, and dry up, and are rubbed off by the animal against the bough of a tree, leaving the dead bone, or horn, attached by its base to the frontal bone; till, after some months, the time for shedding it again comes round, when a repetition of the processes already described takes place.

Bones, even of the same animal, vary much in structure and in hardness, and no doubt in the relative proportion of their component parts, according to the situation in which they are placed and the use to which they are put. Thus the shafts of the long bones, being wanted chiefly for support, are more or less in the form of a hollow cylinder, and the texture of the bone itself is dense and compact. Those parts of bones that form the joints or articulating surfaces by which one is hinged on to another require a considerable space for the joint, and for the attachment of ligaments; but as a degree of strength proportioned to its thickness is not wanted, the structure becomes cellular. A similar structure is observable in the flat bones, which consist of two thin parallel tables of dense bone, having a cellular part interposed between them. Hence, in utensils made of bone, the compact cylindrical ones are generally employed, both as being stronger and admitting of a more uniform and higher polish.

The bones of animals belonging to the same general class of nature are commonly observed to have certain points of general resemblance, by which they may be distinguished from one another, and are applied by man to various uses corresponding with such differences. Thus, the bones of fishes are softer, more flexible, and contain a much larger proportion of jelly and membrane, or, which comes to the same thing, a much smaller proportion of earthy matter, than those of the mammalia or warm-blooded quadrupeds; and the bones of these latter, comparatively dense and hard as they are, fall considerably short in density and hardness of the bones of birds, which, however, are generally too small and thin to be applied to much use in the arts.

Bone undergoes, much more slowly than the soft parts of animals do, the process of spontaneous decomposition; meaning, by this term, that disintegration of a compound which takes place either by the chemical reaction of its ingredients on one another, or by means of air, moisture, and common temperatures. The bones of a human body buried in a churchyard are, perhaps, mostly consumed in twenty or thirty years; yet under favourable circumstances they will endure for a much longer time with but little change. Thus, in the charnel-house at Morat in Switzerland, there still remain many bones of the soldiers of Charles the Bold's army, who perished there in 1438, being 401 years ago. When Sir Christopher Wren was rebuilding St. Paul's Church after the great fire of London, the workmen in digging for the foundations came to the floor of a Roman temple, dedicated to the goddess Diana, on which were the horns of stags and bones of other animals. Tombs of the ancient inhabitants of this island are occasionally opened, in which are found bones that have been deposited there during many centuries; and I have the pleasure of exhibiting to you part of a carved bone spoon (discoloured and passing to a state of decomposition, it is true), which was found in an Etrurian tomb at Vulsinum, in Italy, possibly as ancient as the foundation of Rome. In the valley of the Lea are many peat mosses, the remains of ancient forests, now covered to the depth of several feet with alluvial silt. Many of these have of late years been dug into, on occasion of making docks and other excavations; and in or upon them have been found the osseous remains of boars, stags, and other animals, which have lain there from the time that these creatures roamed wild in the immediate neighbourhood of London. Not only the remains of individuals belonging to species now extant are still found, after being buried for centuries, but the bones of species now extinct, and many of which, judging from the habits of species nearly allied to them and now living, can scarcely exist except in warm climates, are found abundantly in the British islands, and in all parts of Europe. Remains of a large animal of the ox tribe are found in Essex. Elephants, hippopotamuses, and rhinoceroses, differing in many respects from any now known to exist, are also found in the same county, and in other places near London. Hyænas and tigers, also, of extinct species, occur in the cavern of Kirkdale, in Yorkshire, and in other caverns in the west of England; and in certain caverns in Germany are found the remains of two species of bear, differing, in some anatomical details, from any known living species of the same genus. There is no evidence that the human race was contemporary with these creatures; and yet, notwithstanding the enormous length of time that must have elapsed since the deposit of the animals in the places where their bones are now found, many of them are in a state apparently of almost perfect preservation. Membrane and jelly still remain in the bones; but the oil or fat, being uncombined with earthy matter, has disappeared.

In what I have hitherto said, I have alluded very slightly to the use of bone in the arts, which was the ostensible object of the present illustration; for I confess that I have not unwillingly been tempted to enter into the preceding physiological and other details, in order to relieve the dryness of mere technical description. In what remains I shall treat of the practical part of my subject, beginning with an inquiry into the use of bones as articles of food.

All animals that eat flesh will likewise eat bones, provided they are of a size to be easily crushed and masticated by them ; so when a lion or tiger has taken one of the smaller antelopes, I presume he devours many of the bones along with the flesh, leaving only the spine, skull, and horns. But when he has pulled down a horse or buffalo, the case is different; the flesh alone of the animal is sufficient for an ample repast; the leg-bones and ribs are not to be cracked by a single straightforward crush of the jaw ; and the spine, from its awkward shape, as well as by reason of the strong ligaments by which its parts are bound together, may well resist the lazy efforts of an animal already satiated with food,— not to mention that the great length of the canine-teeth in the larger animals of the cat kind, as well as the small number of their grinders, render the act of gnawing both difficult and unnatural to them. The half-picked carcass, therefore, falls to the share of the wolves and hyænas. The former, after tearing off the ligaments of the joints, proceed to separate the bones from each other ; and then, by gnawing, grind off the softer parts of the spongy articulating surfaces, in which they find a wholesome food. The hyæna, with far greater strength of jaw and of teeth than any other animal of his size, goes to work bodily, especially on the ribs and other flat bones, crushing them into large, splintery fragments, and swallowing them in this state, without fear of being choked or injured by their sharp points and rough edges. These two animals, therefore (including the dog, as a sub-species of wolf), are eminently the bone-eaters : the membranous and gelatinous matter of the bone, being dissolved out by their gastric juice from the earthy portion, undergoes the usual process of digestion ; while the latter, apparently unaltered, passes through the intestinal canal, giving to their excrements the well-known appearance of half-dried mortar, and may afterwards be applied to all or any of the purposes for which bone-earth is used.

Man, the cooking animal, extracts nutriment from bones in a different way. When very hard pressed, indeed, he can stave off famine for a while, as Captain Franklin and his party did more than once in their exploratory arctic expedition, by taking bones, which even the wolves had left, and scorching them so as in some degree to subdue their hardness; and thus render it possible to gnaw and masticate them as a succedaneum for food, or, at least, as some alleviation of the agonies of famine.

But the animal matter of bones is best extracted by hot water. Every housekeeper knows that the nutritive quality of meat soups is much increased by boiling the bones together with the meat. In this way, however, only a small proportion of the food contained in the bones is made available; for part of the gelatin is with difficulty, and the membranous part is not at all, soluble in common boiling water; much even of the fat is locked up in cells of the bone, from which it cannot escape except these cells are broken into.

The solid part of the long bones contains very little soluble matter; it would therefore, in most cases, be a matter of economy to exclude them; the advantage to be derived from them by ordinary treatment not being equal to the value of the fuel which they would require. It is from the enlarged extremities of the long bones and their articulating surfaces that the principal supply of nutritive matter is to be derived: these parts, therefore, should be sawed off from the rest and broken into pieces. From the bones of young animals thus treated, boiling water will, in two or three hours, extract the whole or nearly the whole of the soluble matter: but, in the bones of older animals, the gelatin seems to be in a state of condensation approaching to that in which it exists in skin, and therefore requires the long-continued action of boiling water for its separation. By way of experiment, I had the leg-bone of an ox sawed longitudinally and boiled for three or four hours. At the end of this time, the whole of the fat and mucus had been extracted, with part of the jelly. On applying the finger to the cellular part of the bone when wiped dry, I found the surface to be considerably sticky, and, on examining the cells, I found many of them completely filled with a transparent substance scarcely viscid, but much resembling pieces of glue that had been put to soak in cold water; by which, as every one knows, the glue swells exceedingly by absorption of the water, without, however, becoming viscid. A second boiling for three or four hours in fresh water dissolved out a considerable proportion of the gelatin; but still the surface of the bone remained sticky, many of the cells had a glazed surface, and, even after a third repetition of the boiling, only a few even of the superficial cells were quite empty. It is evident, therefore, that we cannot avail ourselves, with any regard to economy of fuel, of the whole of the nutritive matter contained in bones by the action of boiling water applied in the common way. But by means of a digester — that is, a boiler with a steam-tight cover and a safety-valve — we can without hazard raise the temperature of water from 212°, its boiling point in the open air, to 270° or 280°. At a less heat than even the former of these, not only the condensed gelatine but also the membranous part of bones is dissolved, if the bones have previously been reduced to small pieces, and the undissolved residue will be found to be a friable crumbling mass with scarcely any remains of animal matter. It appears that bone soups are thus prepared at present at some of the hospitals and military head-quarters in France, and memoirs have been published, stating the advantage of making a collection of dry bones as part of the provisions of a garrison in case of siege, being a kind of food scarcely susceptible of decomposition or of destruction by rats or mice, and which would require no other magazine than simply making them into stacks and covering them with a roof of thatch or any other material. Complaints, it is true, are made of the burnt flavour which such soups are liable to have, and perhaps it may not be very easy to regulate the temperature of the water in the digester so as to avoid the empyreumatic flavour, and at the same time completely to extract from the bones the animal matter. On this account it is that another scheme has been proposed, namely, to put the bones, after soup has been made of them by boiling in the common way, into a stone trough, and then pour on them very dilute muriatic acid. By repeating this process in the cold a sufficient number of times, the whole of the earthy matter will be dissolved out, and probably without much, if any, injury to the animal matter, which will remain in the form of a porous membrane: by repeated percolations of water the acid would be washed out; or, if a little should remain, a last sprinkling with a solution of carbonate of soda would convert the acid into common salt. The membrane being now dried in the air will acquire a horny hardness, by which it will be rendered almost incapable of spontaneous decomposition, and would probably be found to be much more easily convertible into palatable human food by the common processes of cooking than the entire bone. The plan, to say the least of it, is plausible, provided muriatic acid may be had, as it now may be, at a very small cost.

There is, however, a whole class of animals, the bones of which, without any chemical preparation, are presented to us by nature in a state capable, with very little trouble, of being converted into nourishment. I mean the whole class of fishes. The bones of these creatures contain so little earth, that, by drying and grinding them, a powder is obtained which, when made into cakes with meal, has proved a valuable resource to the people of Norway and Sweden in times of scarcity; and some of them, by simply browning on a gridiron, become quite friable, and, when treated with a proper quantity of pepper and salt, form a very palatable article of food.